20th International Workshop on
Weak Interactions and Neutrinos
June 6-11, 2005, Delphi, Greece

SUSY searches at HERA

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on behalf of H1 and ZEUS Collaborations

Outline

- HERA data taking

- R-parity violation phenomenology at HERA

- squark production
  - first and second generations
  - stop production

- gaugino production:
  - gaugino production in MSSM
  - neutralino production in GMSB

- Summary and Conclusions

HERA data taking

Lumi integrated by experiments so far:

HERA I

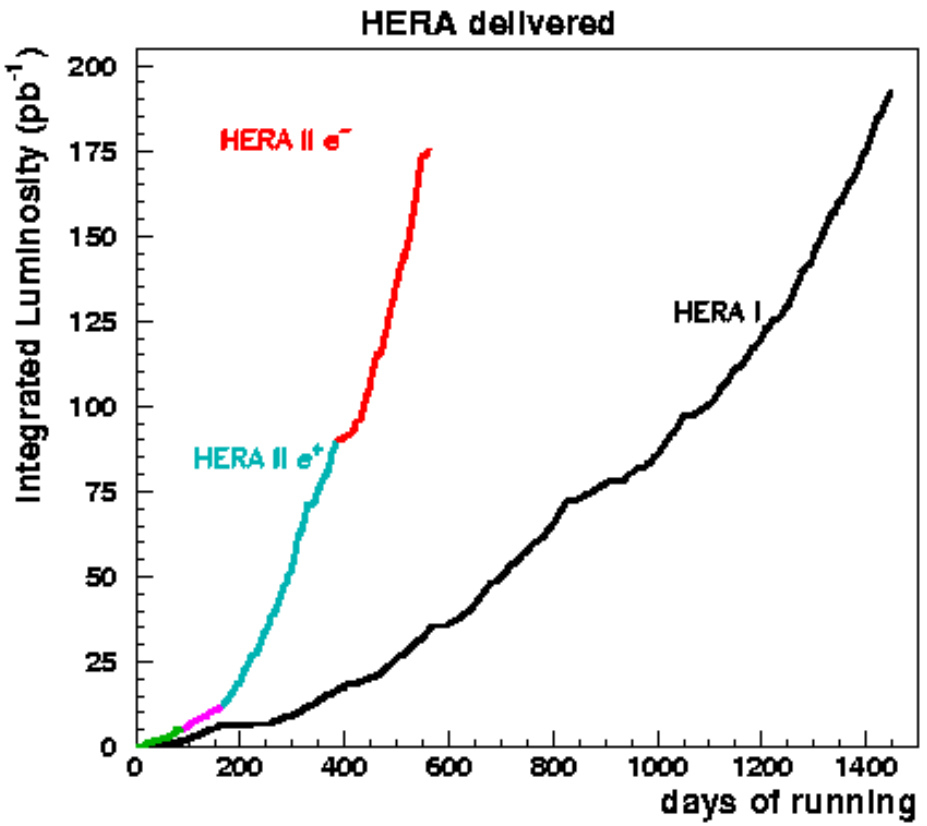
e+p ~ 45/65 pb-1

e-p ~ 15 pb-1

HERA II

e+p ~ 40 pb-1

e-p ~ 60 pb-1



HERA running up to summer 2007

R-parity violation phenomenology at HERA

R-parity violating terms in SUSY superpotential:

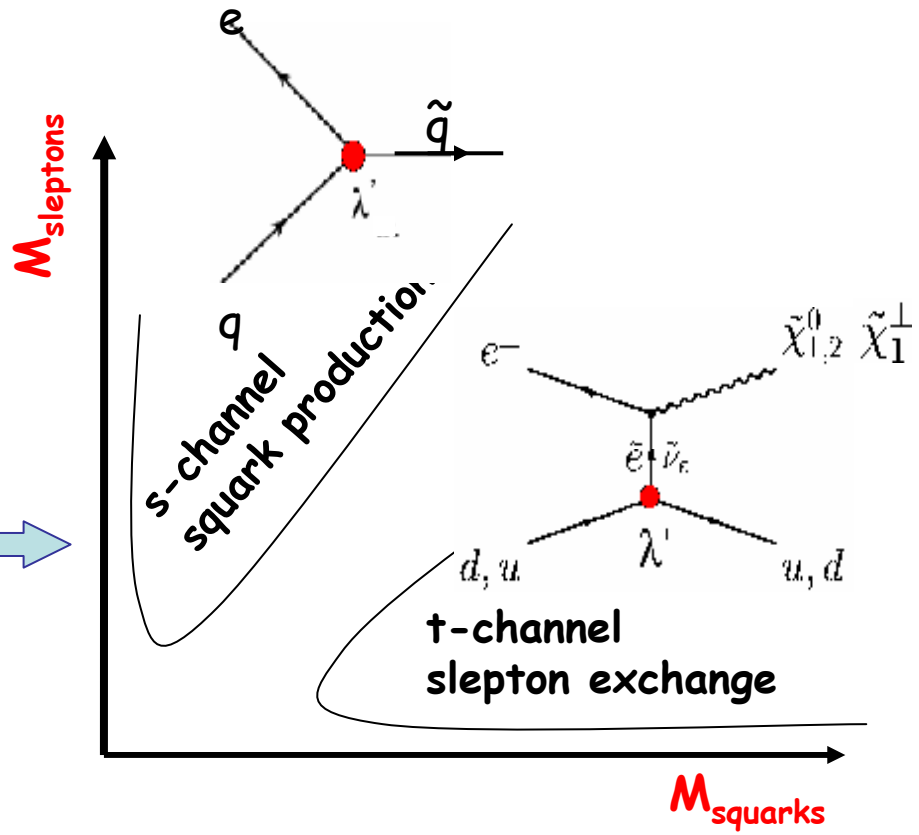
$$W_{\not R_p} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i D_j \bar{D}_k$$

Consequences of R-parity violation:

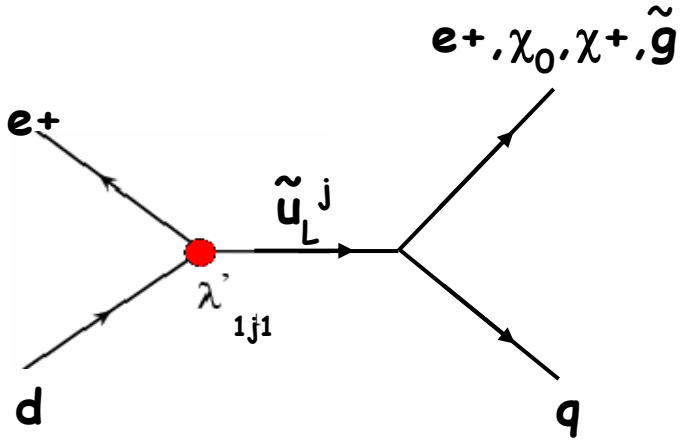
- Sparticles can be single produced at colliders
- LSP not stable

In particular if λ' different from 0
sparticles can be single produced in ep interactions at HERA

Which process dominates depends on sleptons and squarks masses

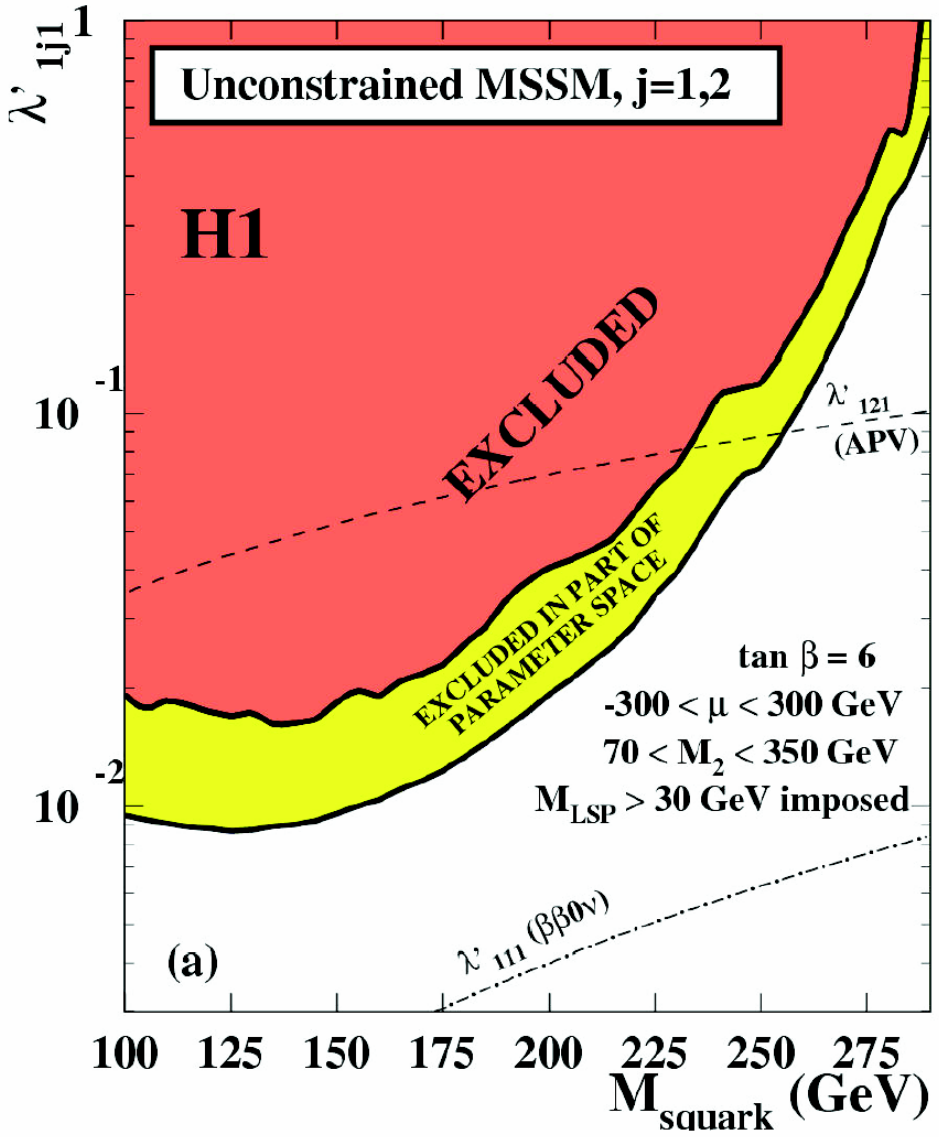


Unconstrained MSSM: 1st and 2nd gen.



- H1 performed a complete search for resonant squark production of all flavors
- squarks with masses up to 275 GeV are excluded at 95% CL for a coupling of em strength

Eur. Phys. J. C36 (2004) 425

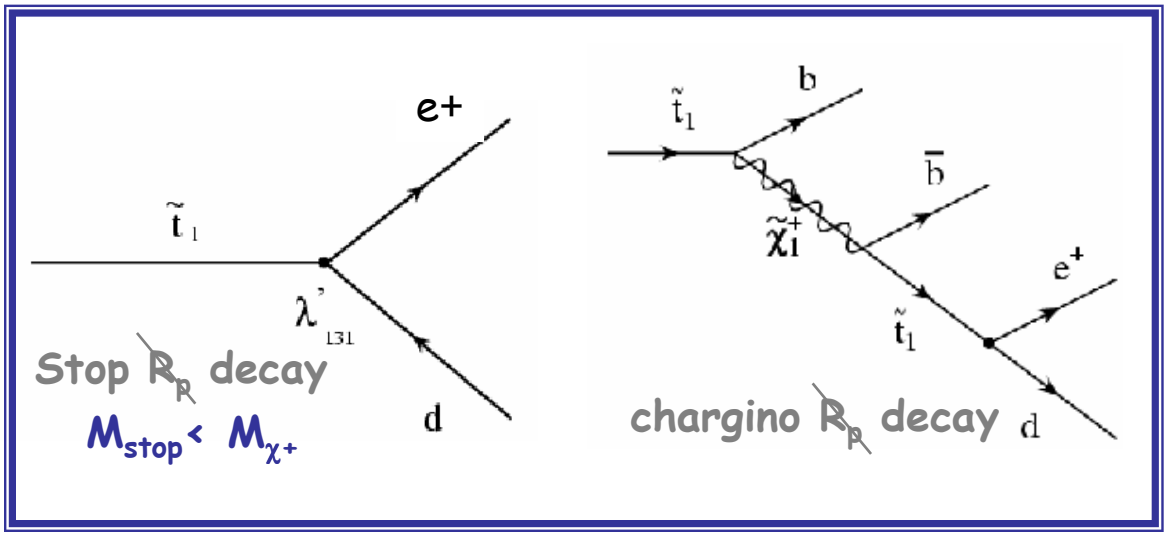


Unconstrained MSSM: stop production

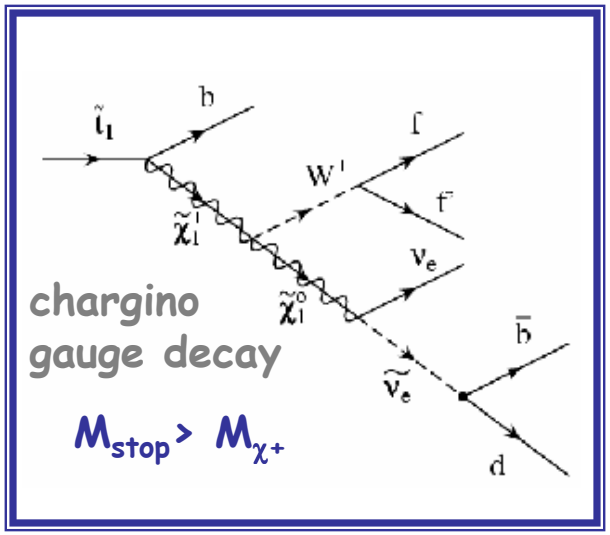
- Stop assumed to be the lightest sfermion
- ZEUS searched for stop production looking at R-parity violating and gauge decays.H1 published similar results (Eur. Phys. J. C36 (2004) 425)

$$W_{\not R_p} \sim \lambda'_{131} e_L \tilde{t}_L \bar{d}_R$$

NC-like channels → e+ jet(s)



CC-like channels → ν jets



almost full branching ratio coverage

Unconstrained MSSM: stop production (contd)

data 99-00: L=65 pb^{-1}

NC-like

- Q^2_{DA} > 3000 GeV^2
- y_{DA} > 0.2 – 0.6

(tuned along the reconstructed mass)

e+ jet:

$P_{t,had}/E_{t,had}$ > 0.8

(enrich the sample of single-jet events)

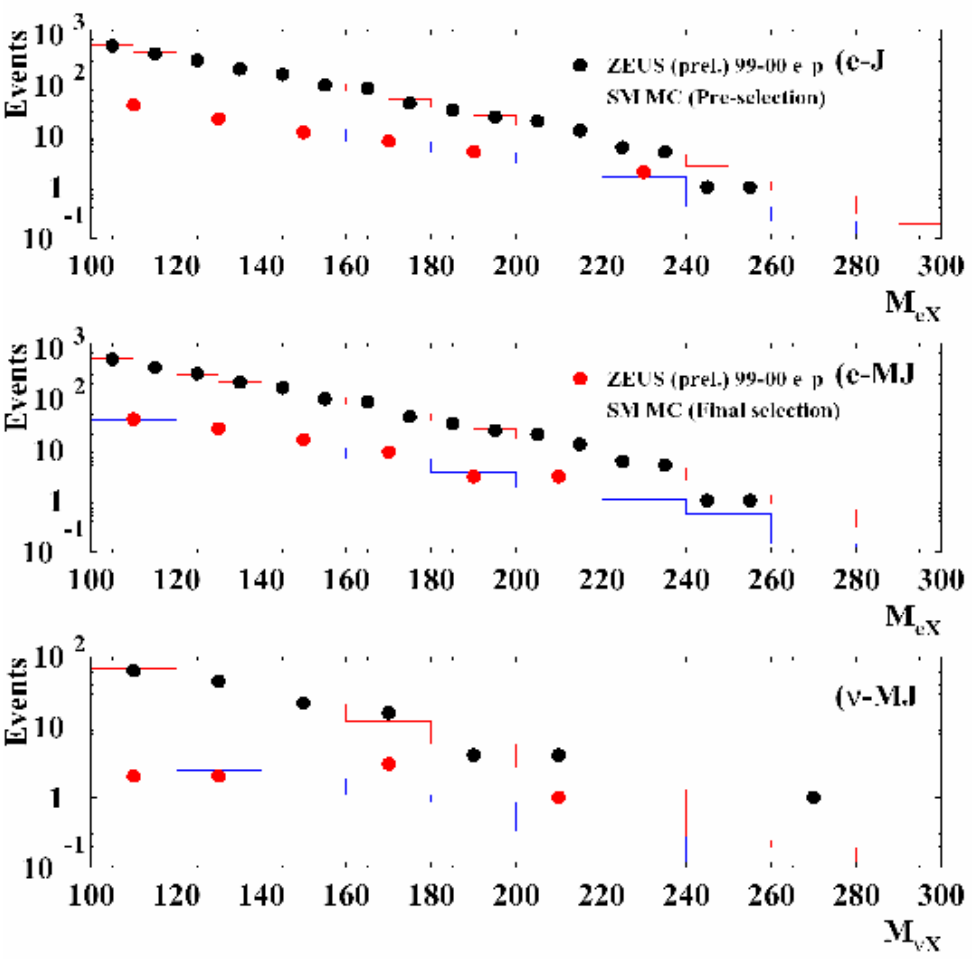
e+ multi-jet:

$P_{t,had}/E_{t,had}$ < 0.8

(enrich the sample of multi-jets events)

CC-like

- ~~P_t~~ > 20 GeV
- E-Pz > 25 GeV
- $P_{t,had}/E_{t,had}$ < 0.4



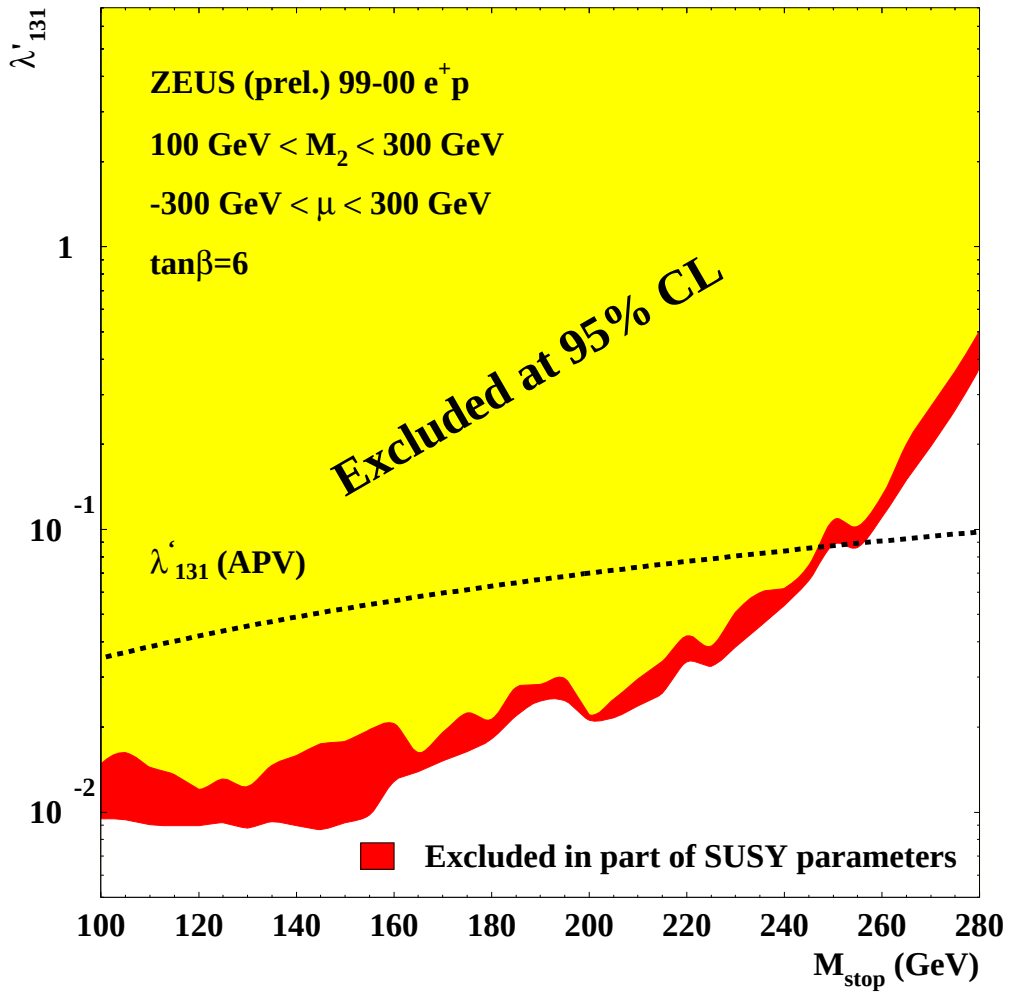
Unconstrained MSSM: stop production (contd)

Limits at 95% CL evaluated combining the three channels

Scenarios where χ_0 is not the LSP or $m_{\chi 0}$ >35 GeV (LEP limits) have been discarded

Stop mass up to 270 GeV excluded for coupling of em strength

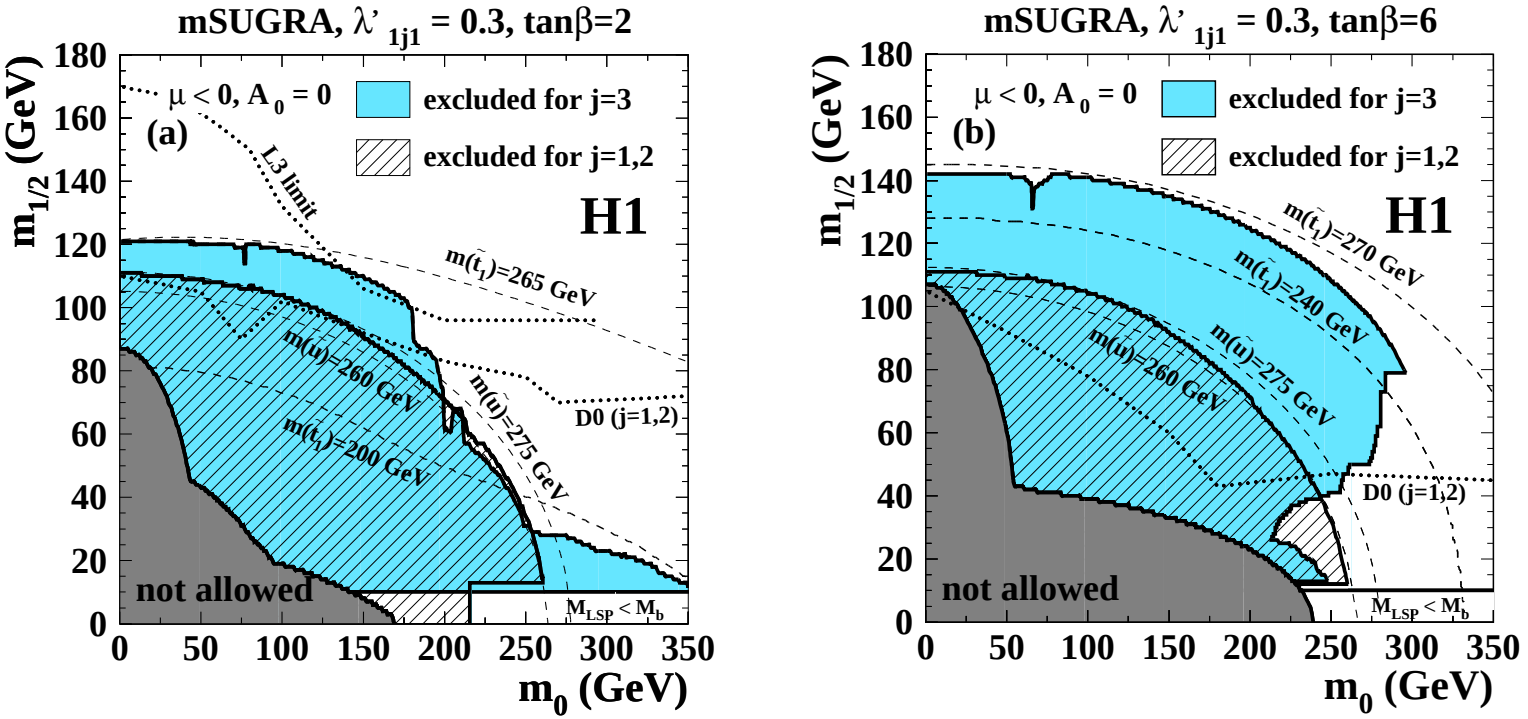
Improve on APV limit for stop masses < 250 GeV



mSUGRA: squark production

Model parameters: m_0 (common scalar mass at GUT scale), $m_{1/2}$ (common gaugino mass), $\tan\beta$, sign(μ) and A_0 (common trilinear coupling).

Assuming λ' of em strength limits on the plane (m_0,$m_{1/2}$) can be evaluated for fixed values of $\tan\beta$, sign(μ) and A_0.



- L3 constraints for χs and sleptons search tipically tighter at low $\tan\beta$
- H1 limits improve on D0 (di-electron analysis) at $\tan\beta$=6

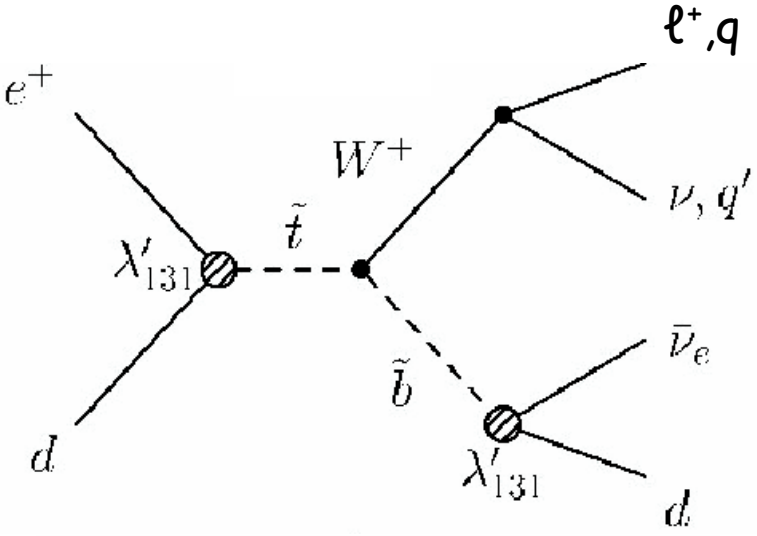
(Eur. Phys. J. C36 (2004) 425)

bosonic stop decay

Scenario considered: $M_{stop} > M_{sbottom}$, squark decay to gauginos forbidden

Complementary to previous stop-search

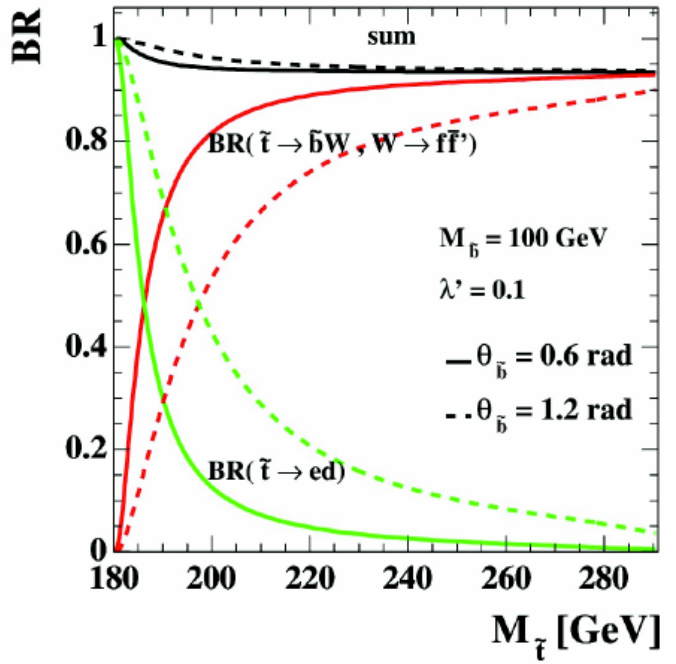
$$W_{\not R_p} \sim \lambda'_{131} e_L \tilde{t}_L \bar{d}_R + \lambda'_{131} \nu_{e,L} \tilde{b}_L \bar{d}_R$$



Stop bosonic decay dominant for $M_{stop} > M_{sbottom} + M_W$

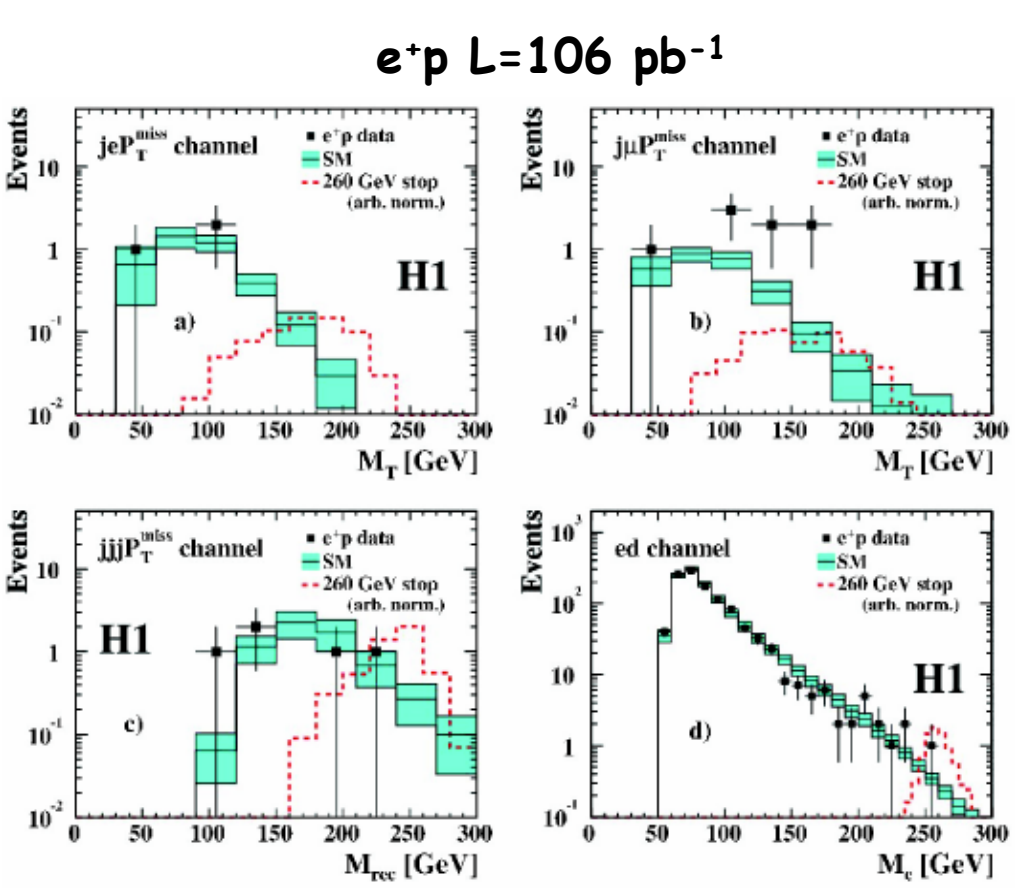
Also analysed the R-parity violating stop decays which dominates for $M_{stop} \sim M_{sbottom} + M_W$

Almost full coverage of branching ratios



Phis. Lett. B599 (2004) 159

bosonic stop decay (contd)



The process produces high-pt leptons in the final state.

Worth to study, remember the excess of such events observed by H1 (not confirmed by ZEUS)

Bosonic stop decay:
Pt(lepton) > 10 GeV
Pt missing > 12 (25) GeV
Pt(jet/s) > 10 / 20,15,10 GeV

R-parity violating decay:
Pt(lepton) > 20 GeV
Pt(jet) > 20 GeV

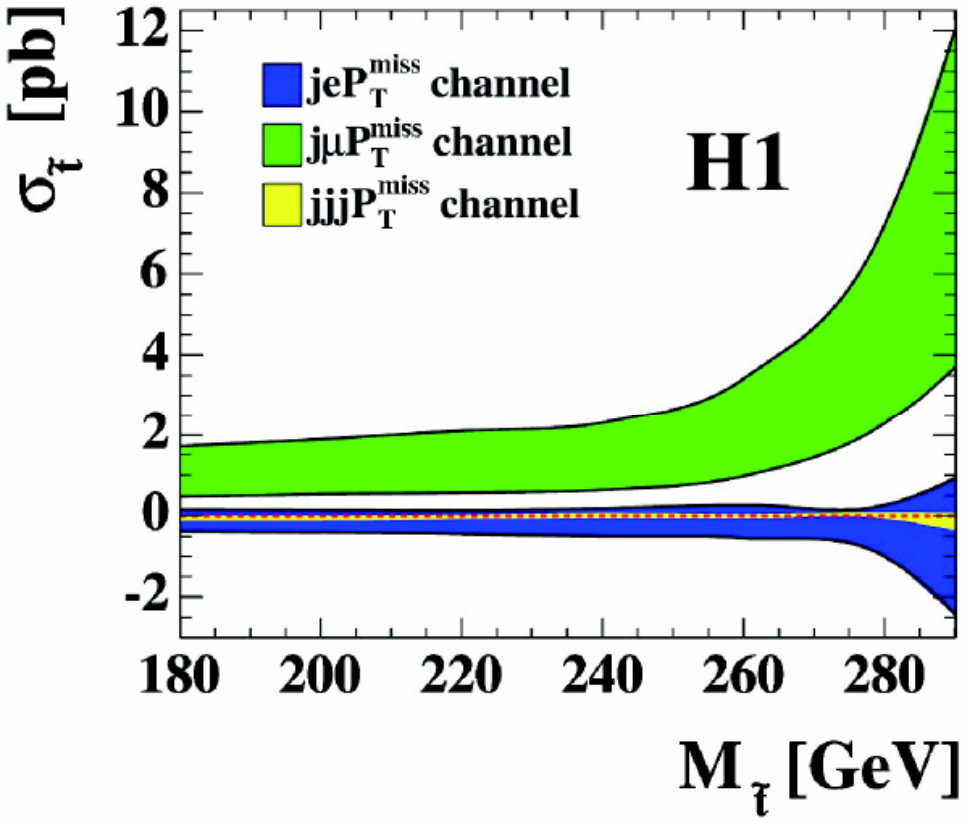
Slight excess in muon channel, but no significant deviation from SM

bosonic stop decay (contd)

Allowed one-sigma range for stop cross-section

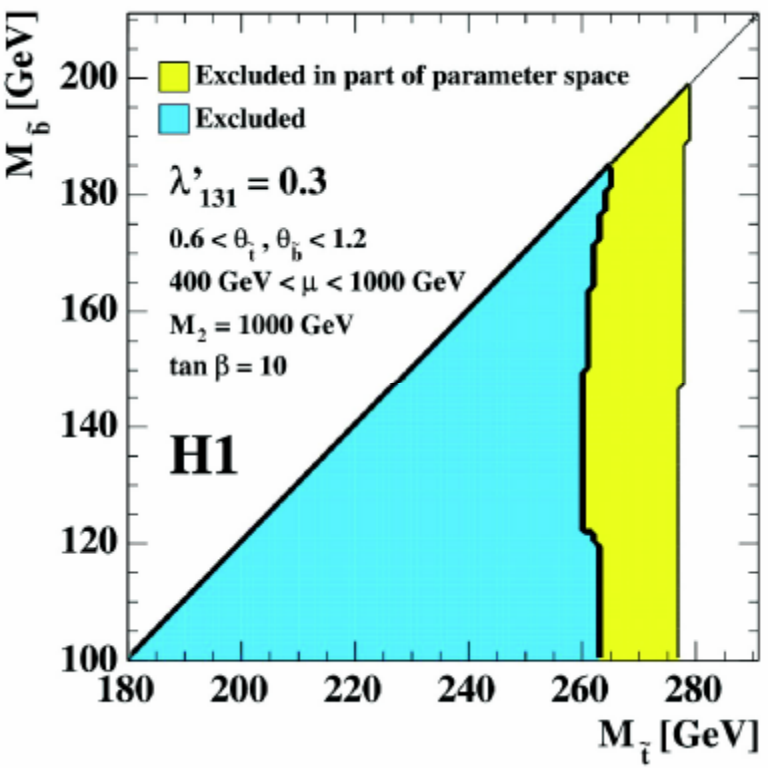
Excess in the muon channel not confirmed by the other channels

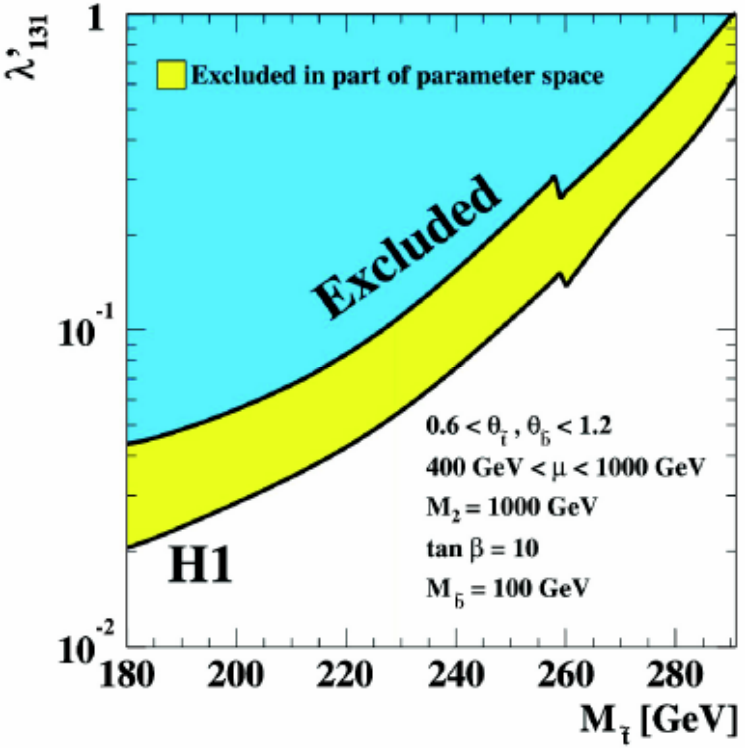
Probability that jets+P_T^{miss} fluctuates up to a level compatible with the muon channel ~ 1%.



Observed H1 excess in high pt isolated leptons cannot be explained by bosonic stop production

bosonic stop decay (contd)





For λ' of em strength stop masses up to 275 GeV excluded

For $M_{sbottom}$=100 GeV, at M_{stop} =200 (250) GeV
allowed coupling domain λ'< 0.03 (0.1)

Gaugino production

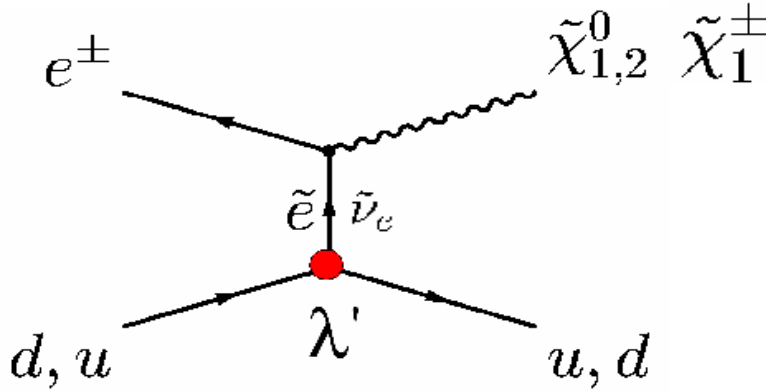
Different scenario considered: $M_{squarks} >> M_{sleptons}$

s-channel suppressed, t-channel slepton exchange dominant

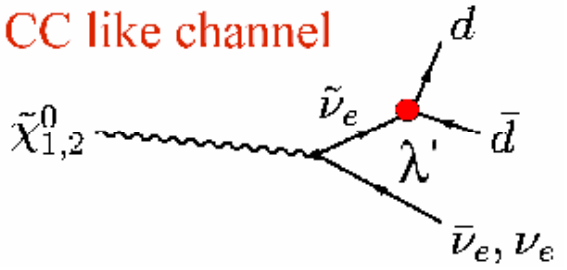
$$W_{R\not p} \sim -\lambda'_{1jk}\tilde{e}_L u^j_L \bar{d}^k_R$$

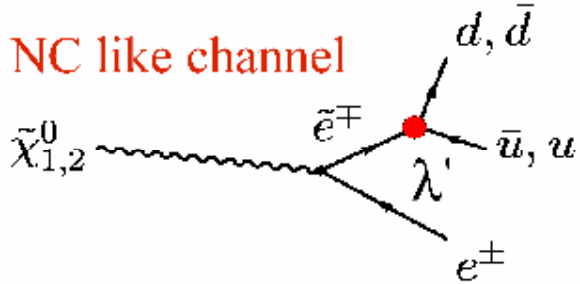
gaugino production

$\sigma \sim \lambda'^2$



gaugino decay
(same channels for χ^0 e $\chi^{\pm}$)





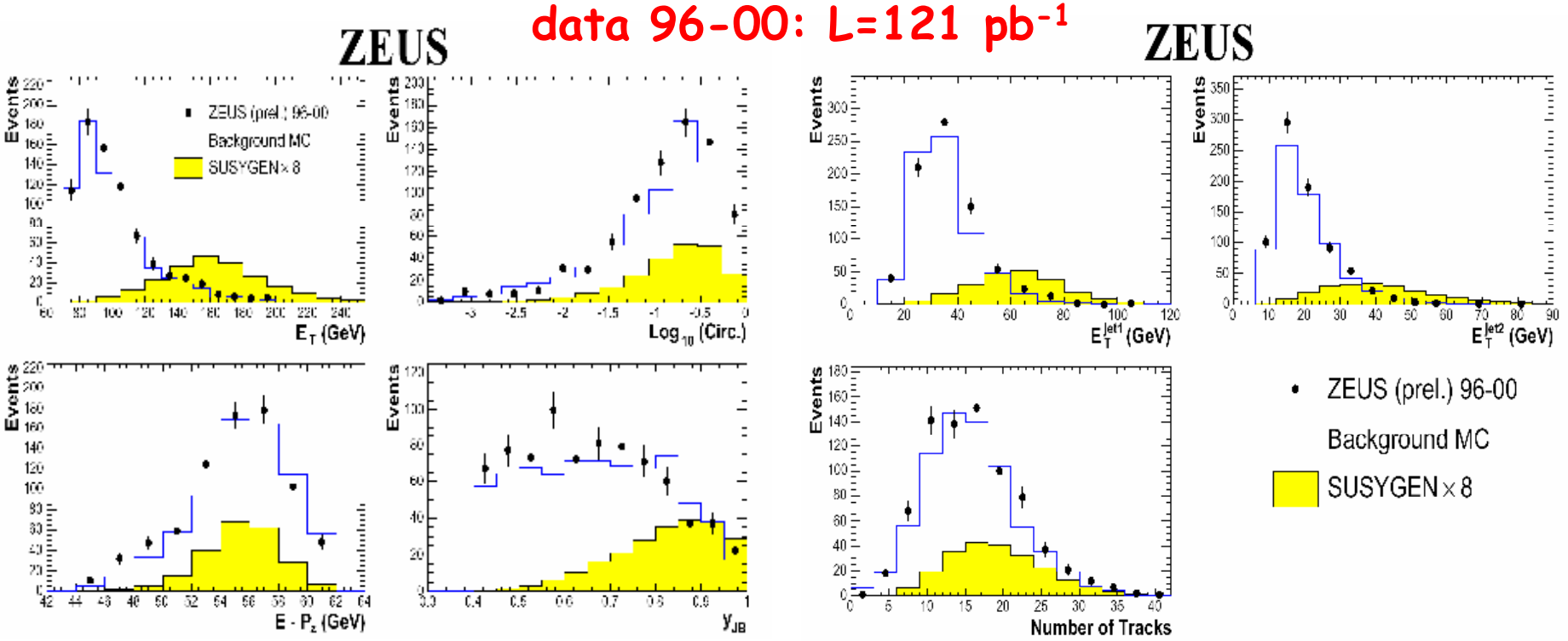
Only NC channel analysed at the moment Br ~ 30-60%

Gaugino production (contd)

Preselection

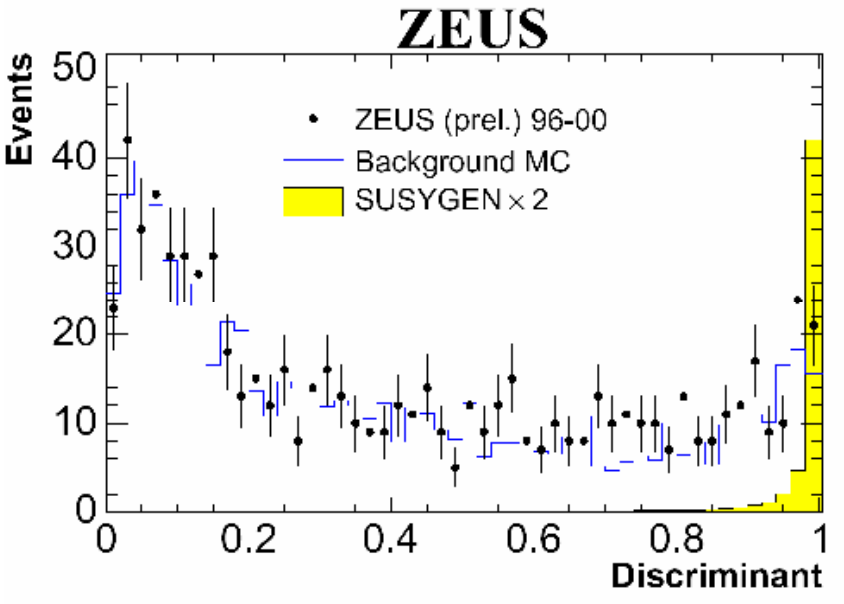
- E_t > 75 GeV, 45< $E-P_z$ < 62 GeV
- y_{jb} > 0.4, Q^2_{jb} > 100 GeV^2
- At least 2 jets: E_t>10 GeV, -0.5<η<2.7
- Electron

data 96-00: L=121 pb^{-1}



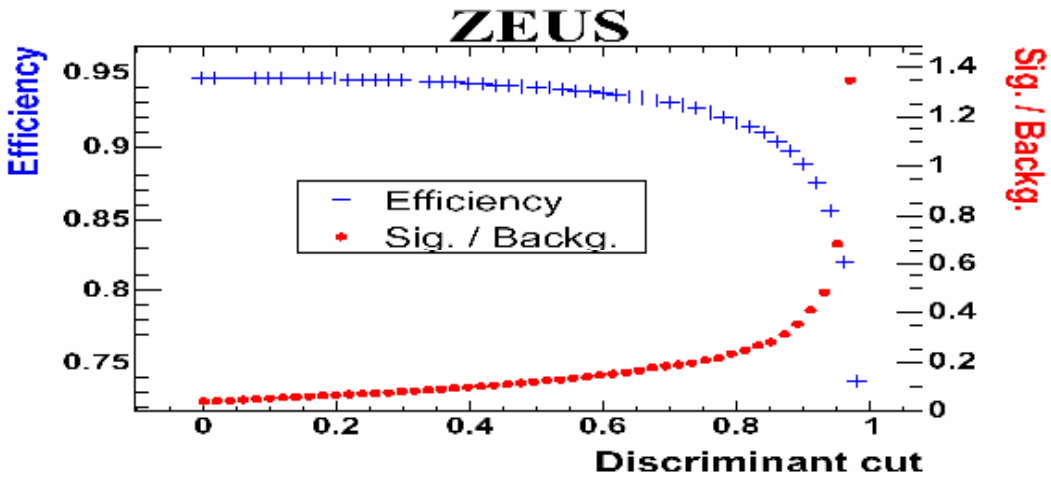
Gaugino production (contd)

In order to improve signal/background discriminant D constructed using:
E_t, circularity, $E-P_z$, y_{jb},
E_t^{jet1}, E_t^{jet2},
number of tracks



No excess seen in data

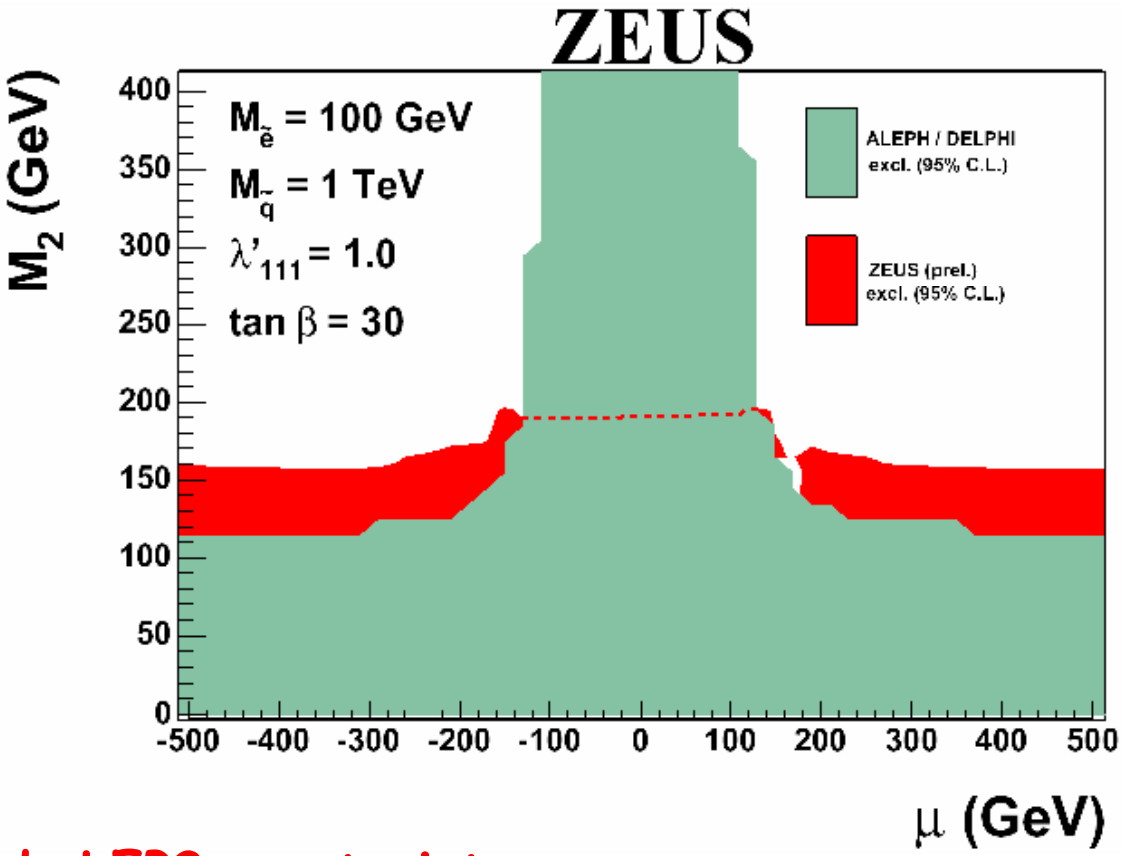
Limit evaluation using the condition D > 0.7



Gaugino production (contd)

MSSM

$\lambda`_{111}=1$, $\tan\beta=30$
$M_{squark}=1$TeV
$M_{selectron}=100$ GeV
$100 < M_2 < 250$ GeV
$-800 < \mu < 800$ GeV



ZEUS extends LEP2 constraints
(Eur. Phys. J. C37 (2004) 129, hep-ex/0406009)
for high $|\mu|$ to $M_2 \sim 160$ GeV

GMSB scenario (light gravitino phenomenology)

In this scenario gravitino is very light (tipical mass < 1 MeV) and is the LSP

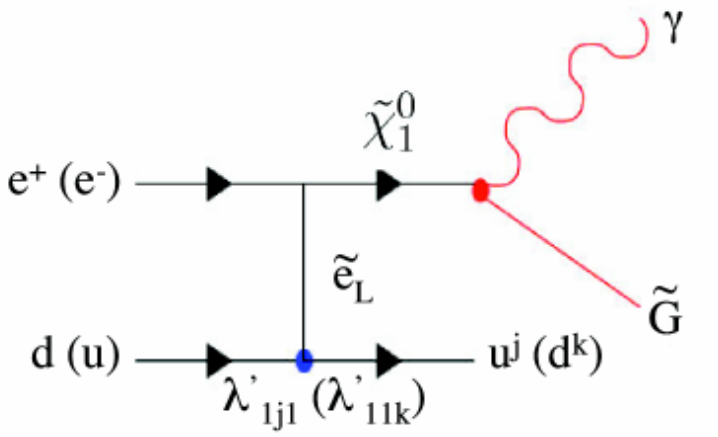
GMSB parameters in addition to SM:

Λ: Mass scale of sparticles M:Mass of messengers particles
N: number of messengers tanβ
sign(μ) $\sqrt{F}$: SUSY breaking scale (related to gravitino mass)

Studied the single neutralino production via selectron exchange:

$$W_{\not R_p} \sim -\lambda'_{1jk}\tilde{e}_L u^j_L \bar{d}^k_R$$

electron/positron beam probe
different couplings



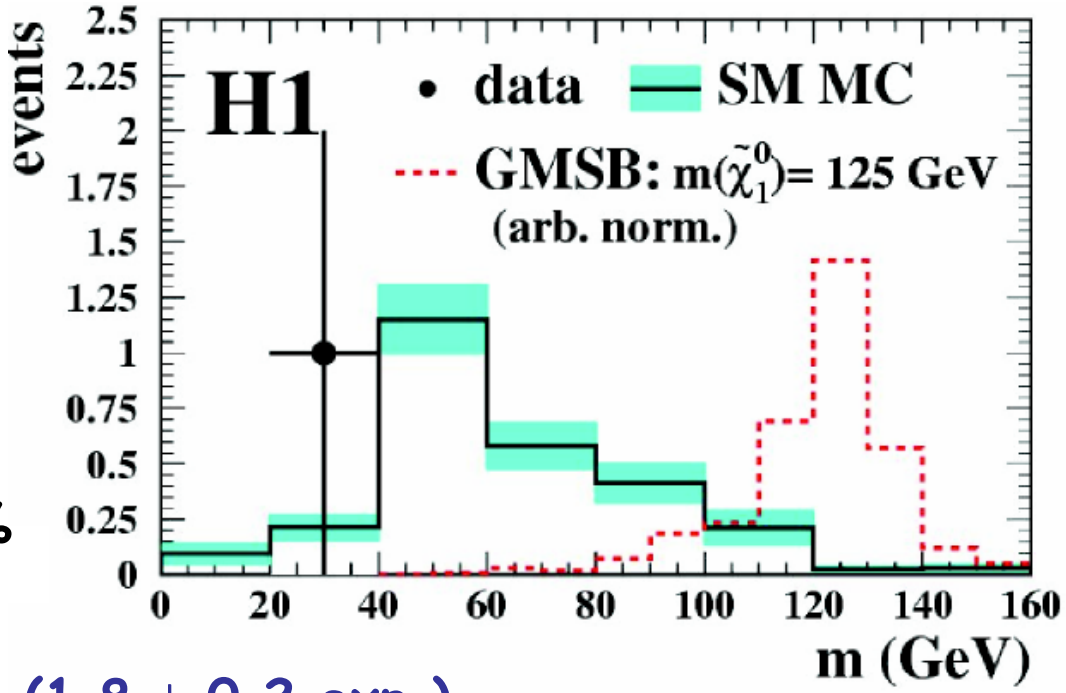
GMSB scenario (contd)

Event signature: γ + missing Pt + jet
Main SM bg.: radiative CC DIS

64 pb^{-1}(e^+p) 14 pb^{-1} (e^-p)

Event selection:
- P_t^{γ} > 15 GeV
(isolated, no matching track)
- P_t^{jet} > 5 GeV
- P_t^{miss} > 25 GeV
- $E-P_z$ > 15 (rejects CC DIS)

Selection efficiency: 10-35%



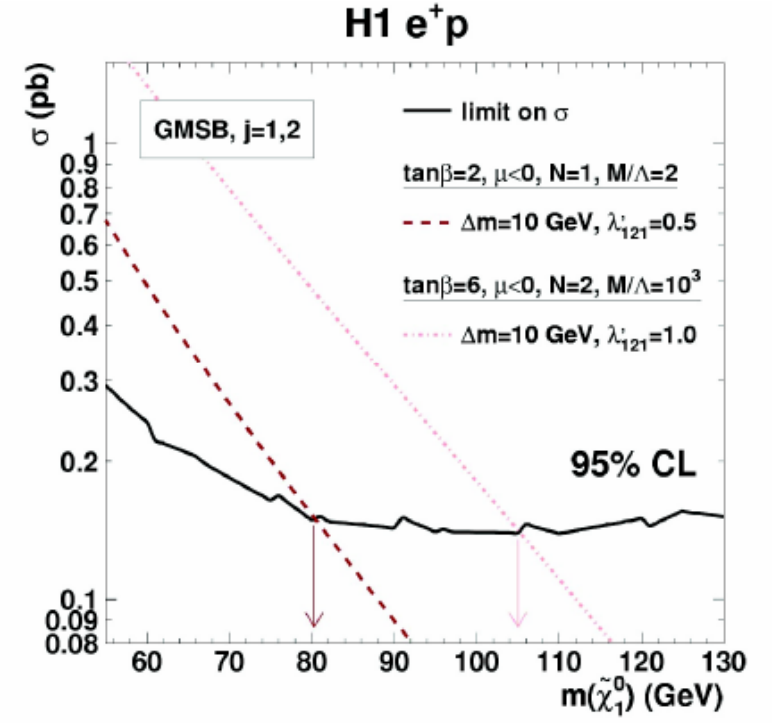
→ e+p: no candidates (1.8 ± 0.2 exp.)

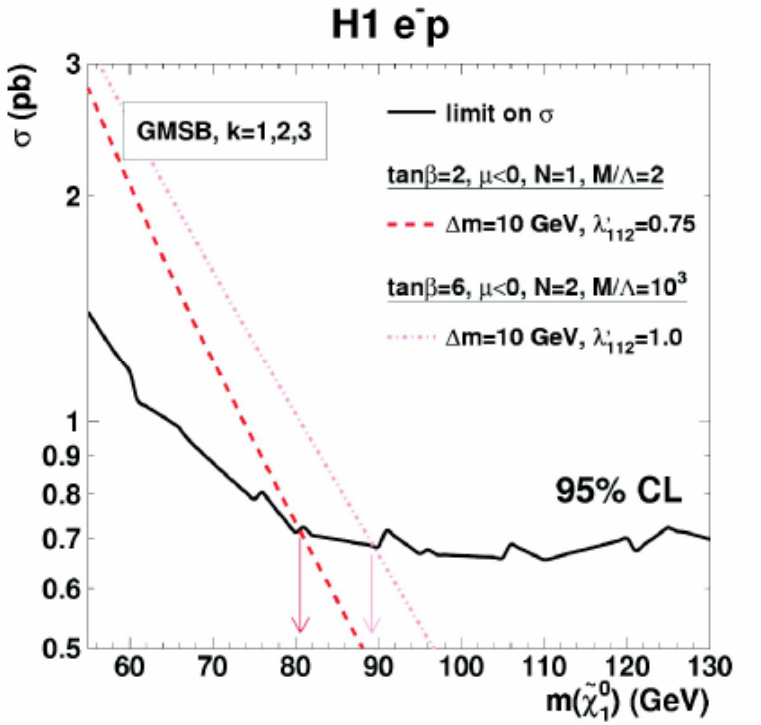
e-p: 1 candidate (1.2 ± 0.2 exp.)
assuming one non-interactiong particle M_{rec}=36±4 GeV

GMSB scenario (contd)

No significant deviation → limits on GMSB scenario at 95% CL

Cross section limits

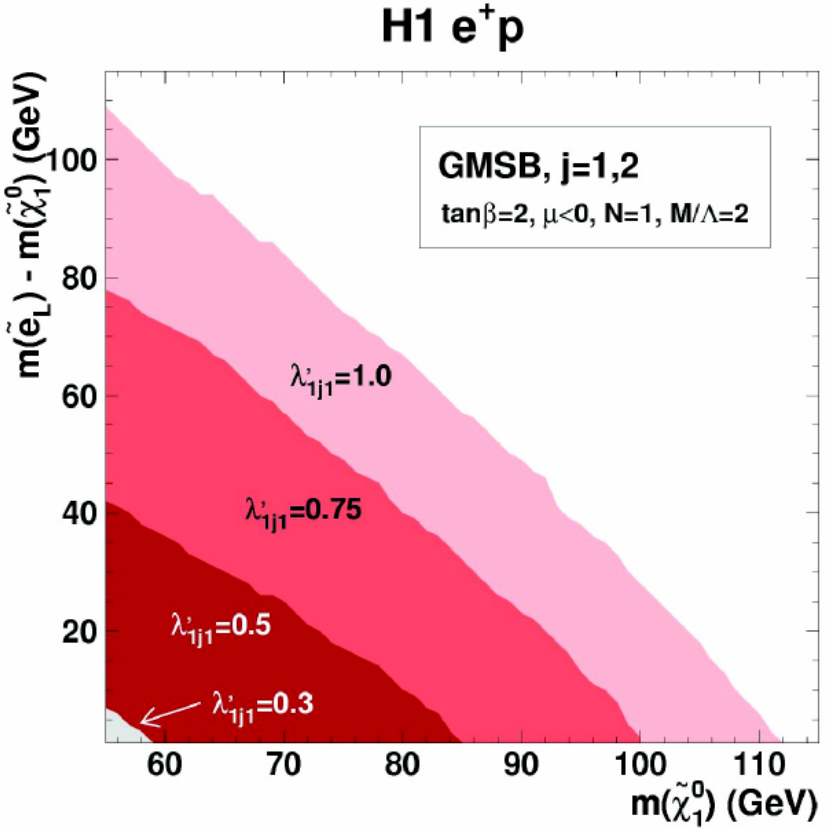


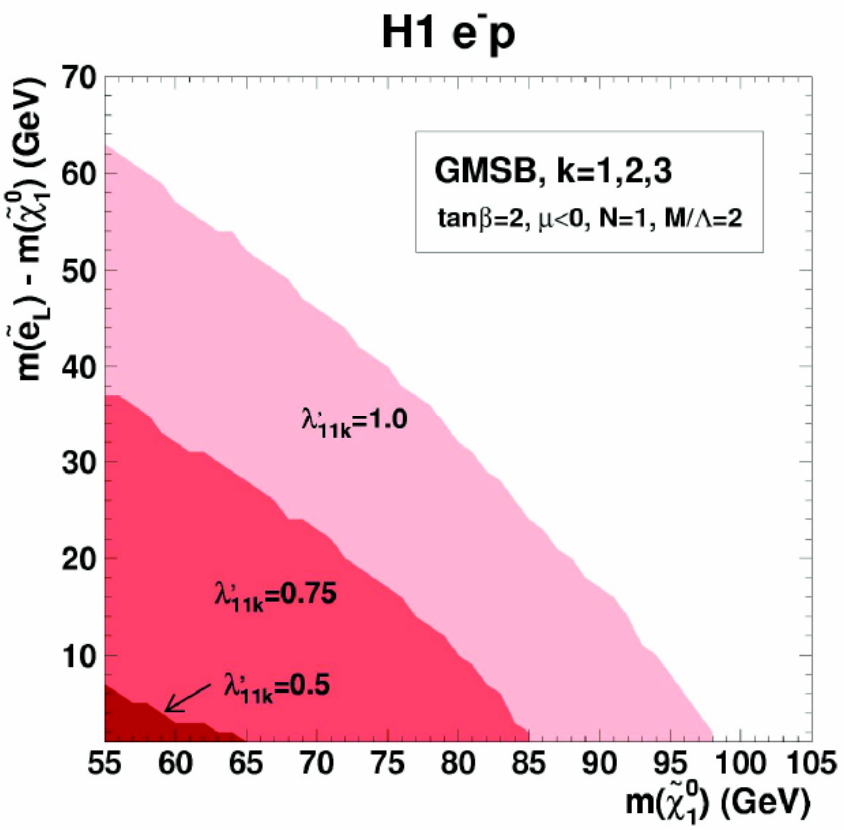


- Limits for different values of λ'_{121} and λ'_{112} also shown for comparison
- Limits less stringent at low neutralino mass due to the lower detection efficiency

GMSB scenario (contd)

Exclusion limits





- Small Δm: neutralino masses up to 112 GeV excluded for $\lambda'_{121}=1.0$
- Large Δm: selectron masses up to 164 GeV excluded for $\lambda'_{121}=1.0$
- For neutralino masses ~ 55 GeV $\lambda'_{1j1}>0.3$ and $\lambda'_{11k}>0.5$ excluded

Summary and Conclusions

- Studied large variety of SUSY scenario assuming Rp violation

  HERA particularly well suited to study squark production
  Squark of all flavors can be excluded up to mass close to the kinematic limit for λ' coupling of em strength.

  But also in scenarios where squarks are much heavier than sleptons
  HERA constraints are complementary and competitive with LEP and Tevatron ones.

- HERA II prospects:

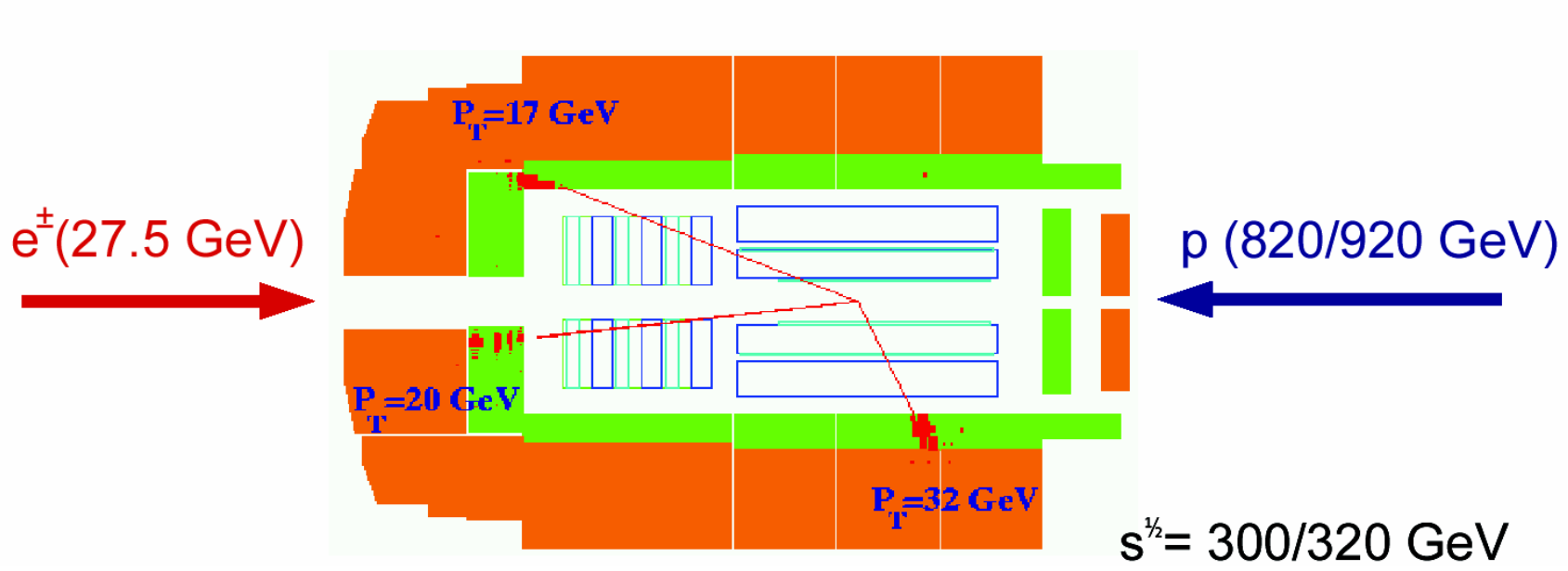
  The future increasing in luminosity will allow to improve the sensitivity especially for those channel which require the electron beam (down squark production, slepton exchange mediated by λ'_{11k})

  Lepton polarization will increase sensitivity for specific process
  $e+_R + d_R \rightarrow \tilde{u}_L \qquad e-_L + u_L \rightarrow d_R$

Other topics

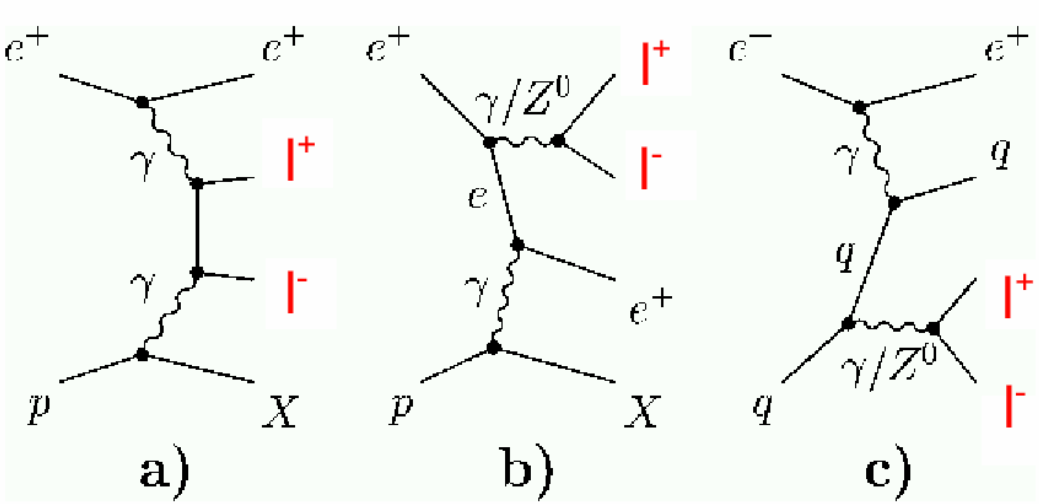
Double charged Higgs

Search for multi-lepton events (e,μ,τ)



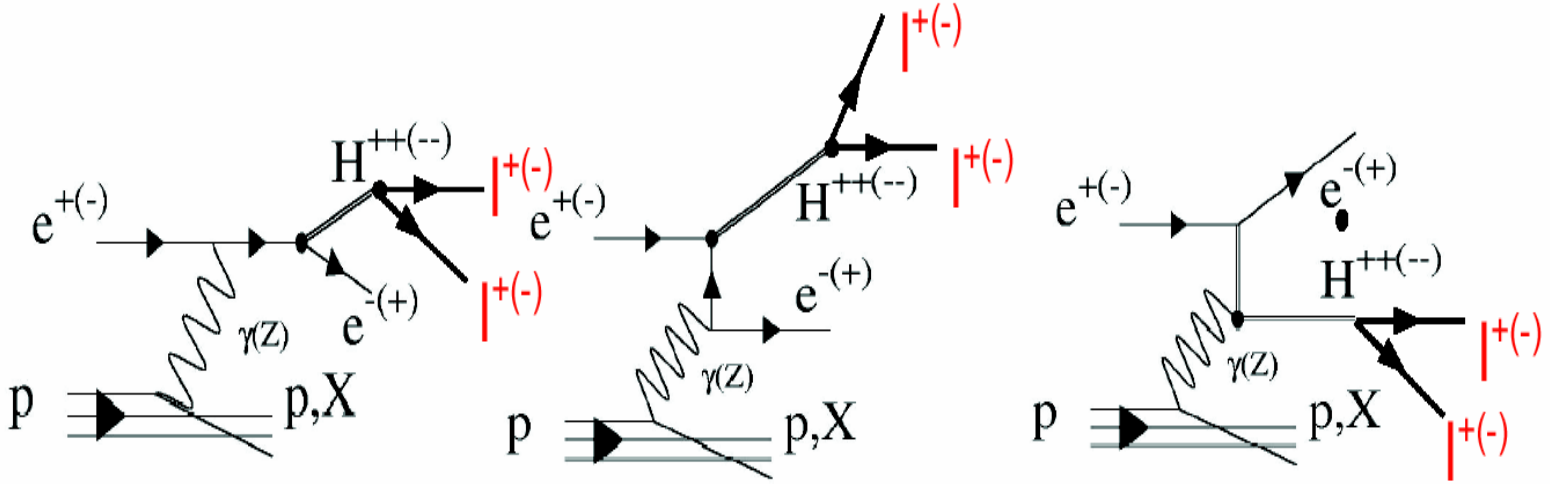
Processes

SM



$\gamma\gamma$ dominant

BSM H^{++}



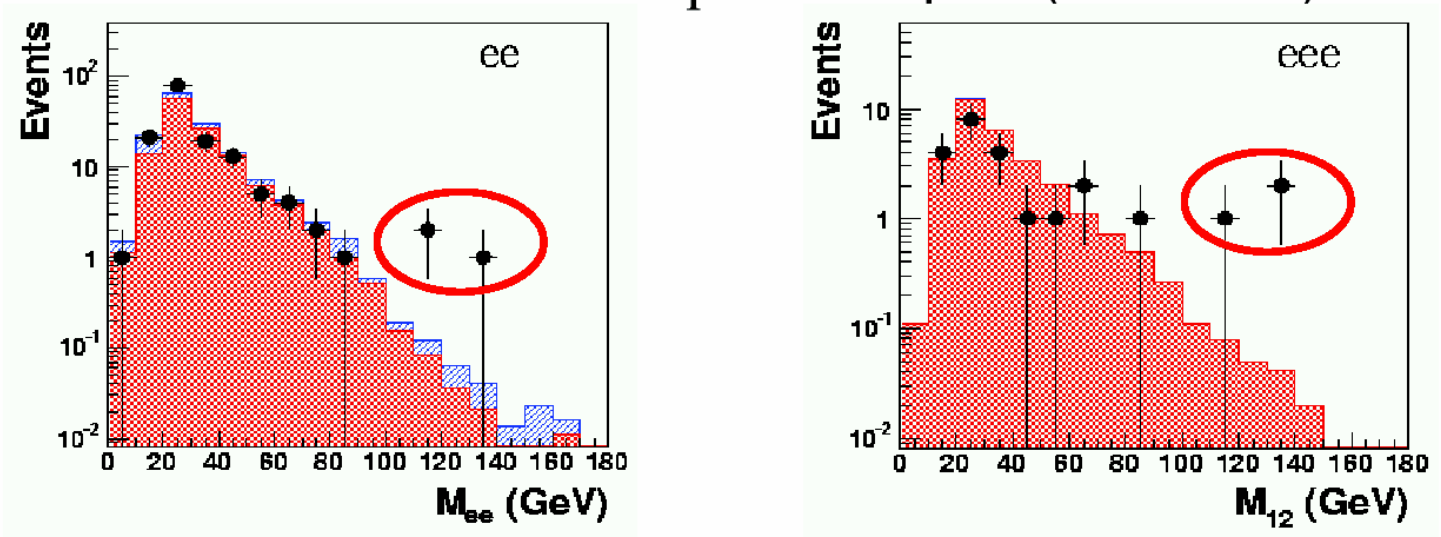
Electron channel

Selection:

2e: Pt > 10, 5 GeV $20^o < \theta_e < 150^o$, isolated track associated

3e: 2e + Pt(third) > 5 GeV $5^o < \theta_e < 175^o$

1996-2004 $e^{\pm}p$ $L=163pb^{-1}$ (ICHEP 04)



(HERA I+II)	data(L=163pb^{-1})	SM	Pair Production (Grape)
ee	147	149.8 ± 24.8	125.5
eee	24	30.4 ± 3.9	30.4

⇒ good agreement with SM

Bg:

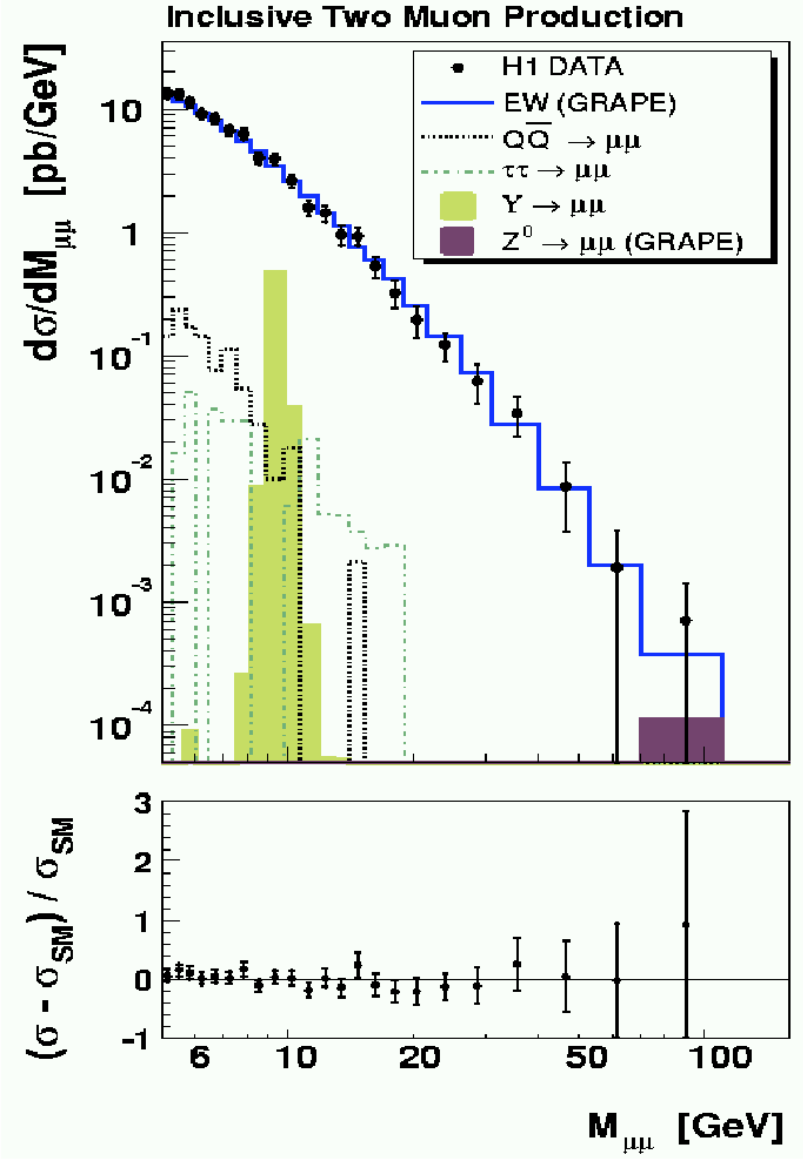
compton ep → eγX

NC ep → eX

(HERA I+II)	data(L=163pb^{-1})	SM	Pair Production (Grape)
ee M_{12}>100 GeV	3	0.44 ± 0.10	0.32
eee M_{12}>100 GeV	3	0.31 ± 0.08	0.31

⇒ excess at high invariant mass

Muon channel



High-Pt muons (similar selection as for electron channel → no excess

Results (L=114 pb^{-1}):

H1 (L=115pb^{-1})	data	SM
μμ	40	39.9 ± 4.2
μμe	16	14.9 ± 1.6

→ no μμμ event

04/05 electron data

2004-2005 e^-p (Preliminary)

(HERA 04/05)	data(L=21 pb^{-1})	SM	Pair Production (Grape)
ee	21	21.1 ± 1.9	17.2
eμ	8	10.8 ± 2.5	6.6
eee	1	4.2 ± 0.7	4.2
eμμ	6	5.4 ± 0.9	5.4

No new event with mass > 100 GeV

H^{++} selection

Selection:

ee, μμ, eμ

Ask for lepton charges compatible with beam charge

(two high pt lepton with same charge equal to the lepton beam)

in addition to multilepton selection

⟹ 1 ee event survive

ττ

Search for all tau decay channels (L=65pb-1)

e,μ,jet identification:

Isolation, Pt > 10, 5 GeV, $20^\circ < \theta < 150^\circ$

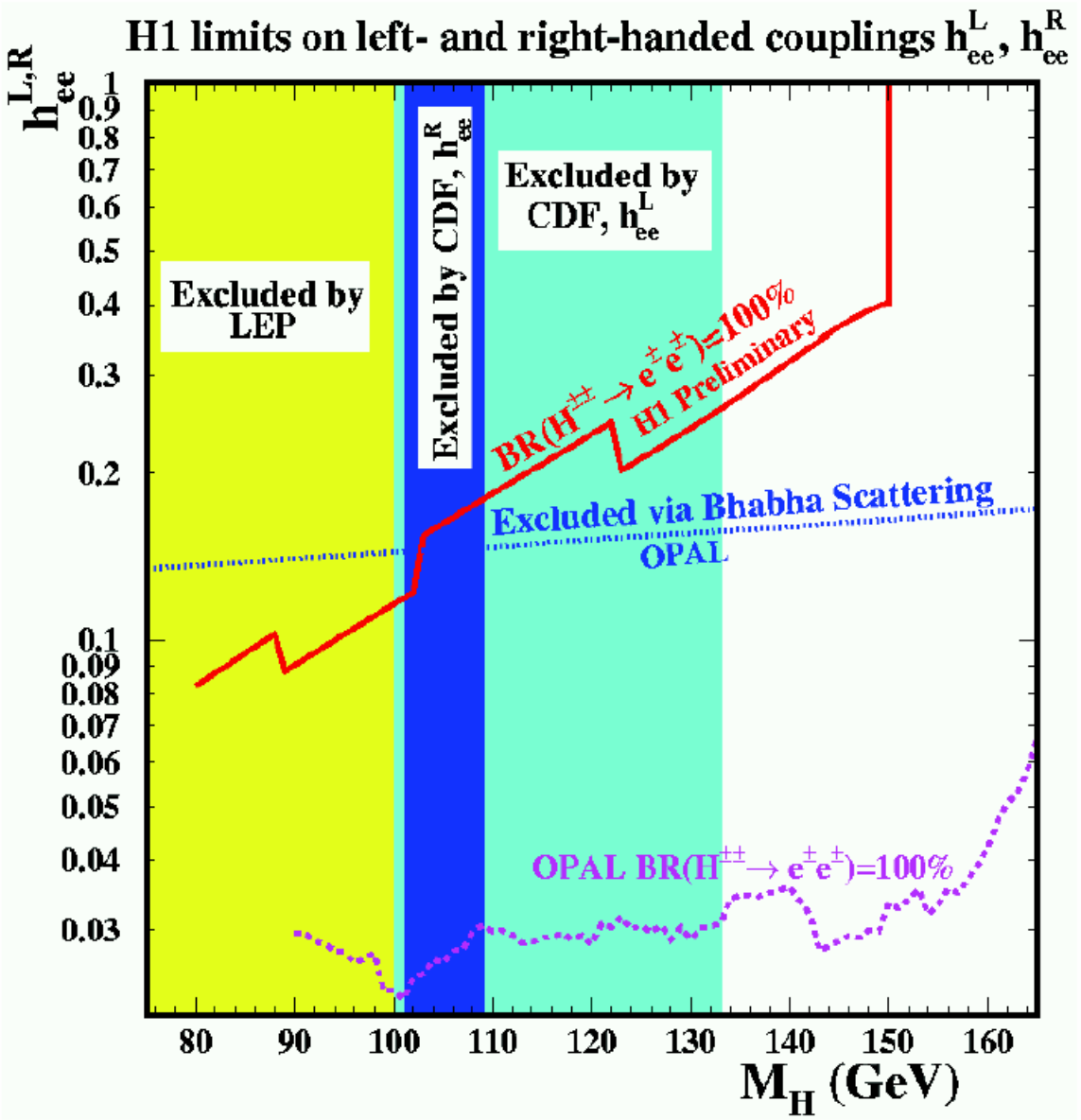
Charge requirement

final state	ττ preselection data	SM	ττ (Grape)	final selection data	SM
eμ	0	0.29 ± 0.03	(0.11)	0	0.09 ± 0.01
ej	0	1.20 ± 0.24	(0.31)	0	0.78 ± 0.16
μj	0	0.25 ± 0.05	(0.16)	0	0.03 ± 0.01
jj	1	0.38 ± 0.10	(0.16)	0	0.13 ± 0.08

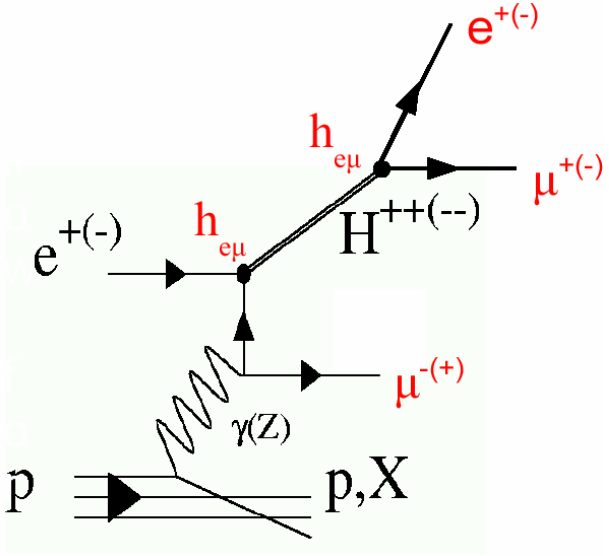
Agreement with SM

HERA I 1996-2000

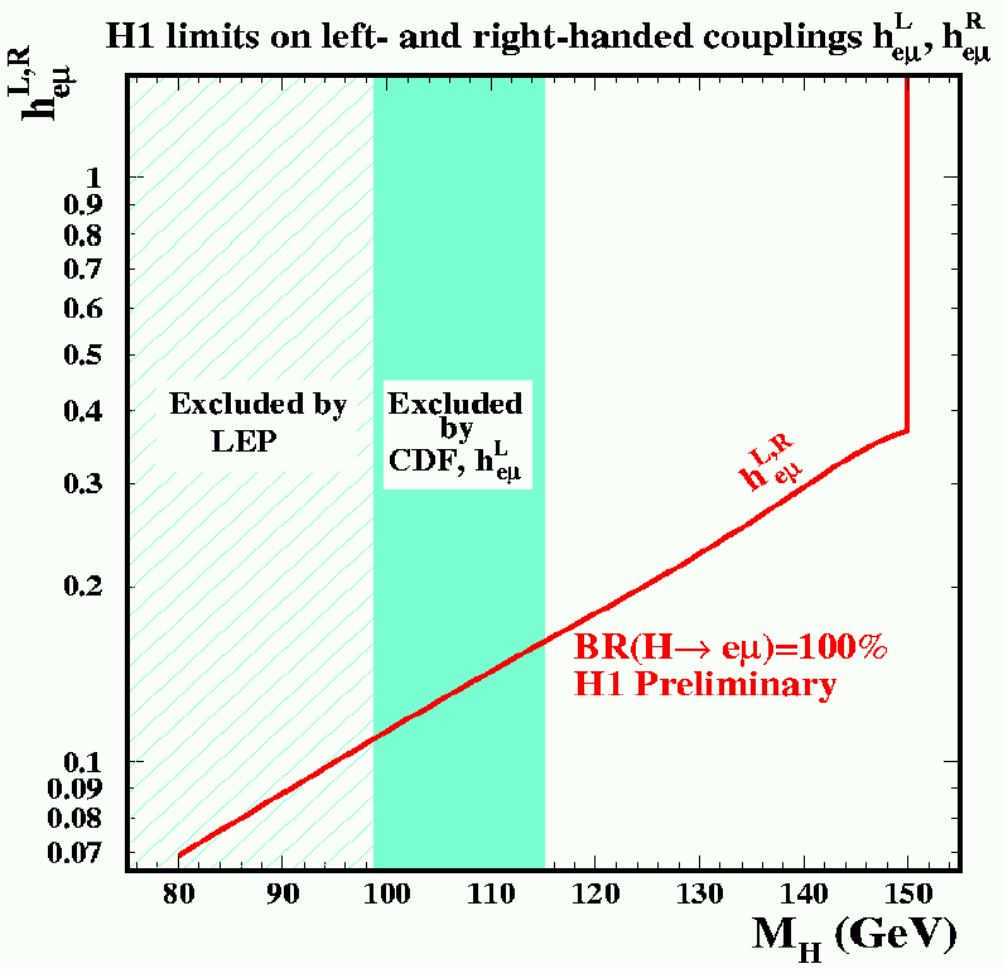
h_{ee} dominant



LFV coupling

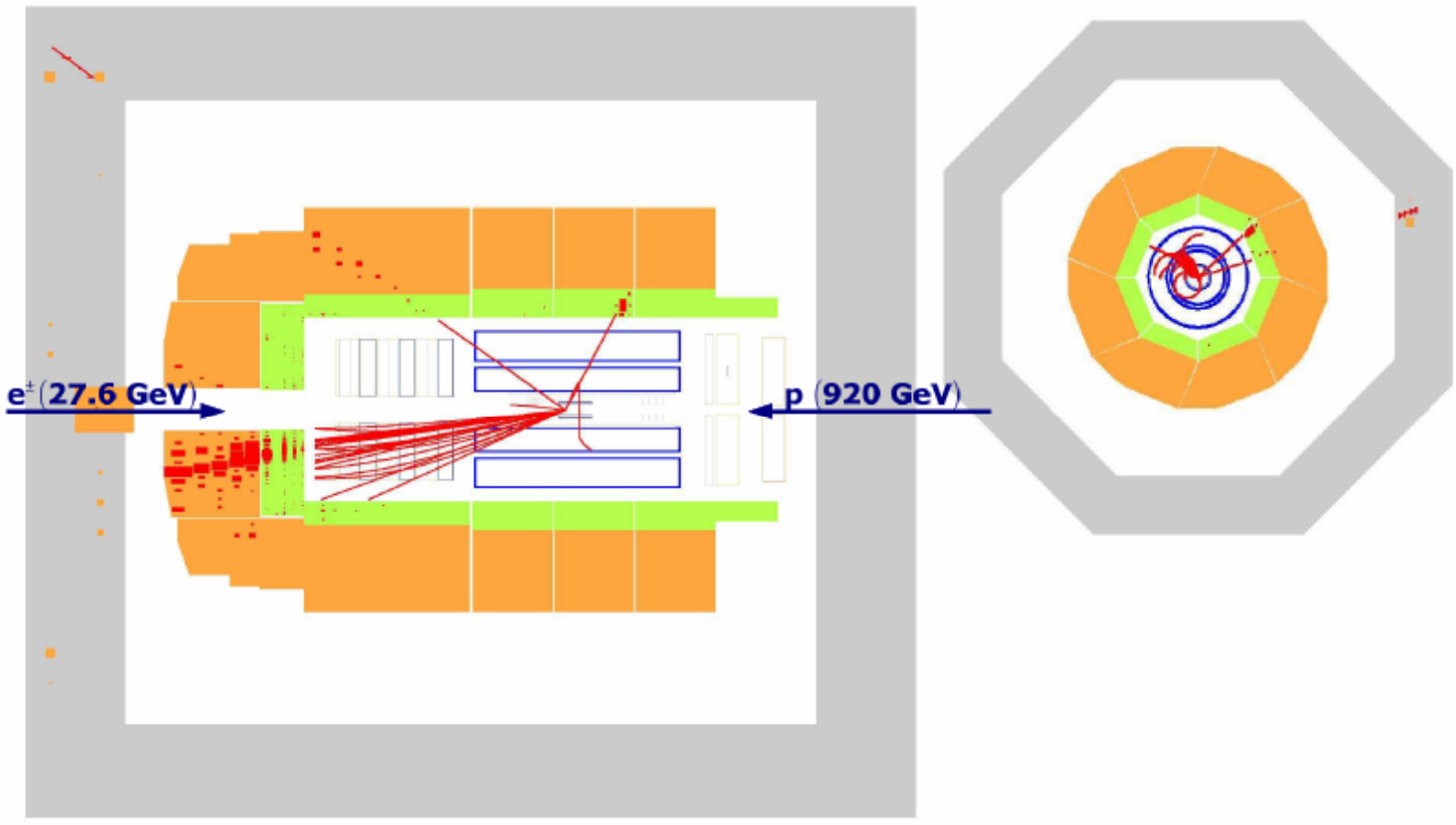


HERA I 1996-2000



Limit of LFV coupling $h_{e\mu}$ extended to region not excluded by other exps.

Isolated high pt leptons



Event selection

Selection of e,μ Events

Lepton within Detector Acceptance	$5° < \theta_l < 140°$
High Transverse Momentum of Lepton	$P_T^l > 10$ GeV
Lepton Isolation w.r.t. other Particles	$D_{jet} > 1$, $D_{track} > 0.5$
Large Missing Transverse Momentum	$P_T^{miss} > 12$ GeV
Acoplanarity	$\Delta\varphi_{\mu\text{-}X} < 170°$ $\Delta\varphi_{e\text{-}X} < 160°$

Selection of τ Events

Tau-Jet within Detector Acceptance	$20° < \theta_{jet} < 120°$
High Transverse Momentum of Lepton	$P_T^{jet} > 7$ GeV
One-Prong Tau Decay	$R_{jet} < 0.12$, only 1 Track
Lepton Isolation w.r.t. other Particles	implicit
Large Missing Transverse Momentum	$P_T^{miss} > 12$ GeV
Acoplanarity	$\Delta\varphi_{jet\text{-}X} < 170°$

HERA I

e^+p (1994-2000) 105 pb^{-1}

	Electron obs./exp. (W)	Muon obs./exp. (W)
All P_T^X	10/9.85 ± 1.27 (73%)	8/2.55 ± 0.44 (88%)
P_T^X > 25 GeV	4/1.48 ± 0.25 (86%)	6/1.44 ± 0.25 (90%)

e^-p (1998/99) 14 pb^{-1}

All P_T^X	1/1.69 ± 0.22 (59%)	0/0.37 ± 0.06 (78%)
P_T^X > 25 GeV	1/0.28 ± 0.04 (64%)	0/0.24 ± 0.04 (75%)

$e^\pm p$ (1996-2000) 108 pb^{-1}

	Tau obs./exp. (W)
All P_T^X	5/5.81 ± 1.36 (15%)
P_T^X > 25 GeV	0/0.53 ± 0.10 (49%)

HERA II

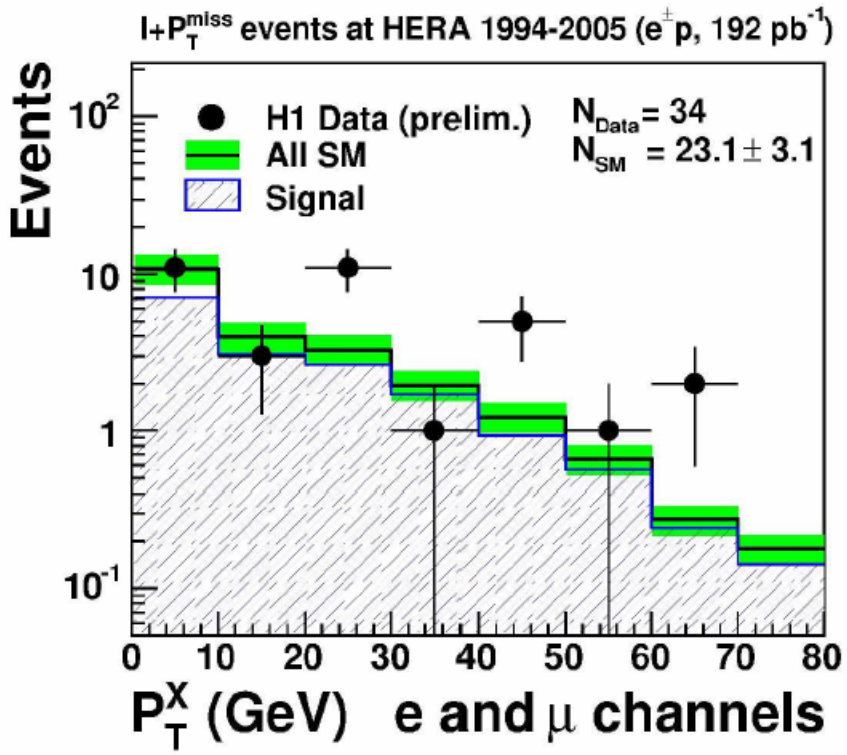
e^+p (2003/04) 53 pb^{-1}

	Electron obs./exp. (W)	Muon obs./exp. (W)
All P_T^X	9/4.75 ± 0.76 (65%)	1/1.33 ± 0.19 (77%)
P_T^X > 25 GeV	5/0.84 ± 0.19 (69%)	0/0.85 ± 0.13 (74%)

e^-p (2004/05) 21 pb^{-1}

All P_T^X	5/2.15 ± 0.33 (63%)	0/0.59 ± 0.09 (76%)
P_T^X > 25 GeV	1/0.30 ± 0.05 (77%)	0/0.36 ± 0.06 (72%)

HERA I+II



e$^{\pm}$p data (1994-2005) 192 pb^{-1}

	Electron obs./exp. (W)	Muon obs./exp. (W)	Tau① obs./exp. (W)
All P_T^X	25/18.3 ± 2.5 (70%)	9/4.8 ± 0.8 (85%)	5/5.8 ± 1.4 (15%)
P_T^X > 25 GeV	11/3.0 ± 0.6 (81%)	6/3.0 ± 0.6 (86%)	0/0.5 ± 0.1 (49%)

① e$^{\pm}$p (1996-2000) 108 pb^{-1}

ZEUS-H1 comparison

$e^{\pm}p$ data (1994-2000) 130 pb^{-1}

	Electron obs./exp. (W)	Muon obs./exp. (W)	Tau obs./exp. (W)
All P_T^X	24/20.6 $^{+1.7}_{-4.6}$ (17%)②	12/11.9 $^{+0.6}_{-0.7}$ (16%)②	3/0.40 ± 0.12 (43%)
P_T^X > 25 GeV	2/2.90 ± 0.6 (45%)	5/2.75 ± 0.21 (50%)	2/0.20 ± 0.05 (49%)

② Preselection

$e^{\pm}p$ data (1994-2005) 192 pb^{-1}

	Electron obs./exp. (W)	Muon obs./exp. (W)	Tau① obs./exp. (W)
All P_T^X	25/18.3 ± 2.5 (70%)	9/4.8 ± 0.8 (85%)	5/5.8 ± 1.4 (15%)
P_T^X > 25 GeV	11/3.0 ± 0.6 (81%)	6/3.0 ± 0.6 (86%)	0/0.5 ± 0.1 (49%)

① $e^{\pm}p$ (1996-2000) 108 pb^{-1}

Limits on single top prduction